HYDROLOGY COMPONENT
GAPP CORE PROJECT

FY2004 ACCOMPLISHMENTS

FY2005 STATEMENT OF WORK

PROPOSED FY2005 BUDGET

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February 11, 2005

GAPP Core Project: <u>OHD</u> Component

FY2004 Accomplishments and FY2005 Work Plan

One of the primary objectives of GAPP is "To interpret and facilitate the transfer of the results of improved seasonal predictions to users for the optimal management of water resources." This objective is an update to the GCIP objective "Improve the utility of hydrologic predictions for water resources management up to seasonal to inter-annual time scales." To accomplish the GAPP objective, it is necessary to understand: (i) what kinds of forecast products are most useful to water resources agencies; (ii) how this information would be used in water management decisions; and (iii) how this information can best be produced, and transferred to water managers. Addressing these issues will, in turn, help focus related science needs (e.g., development of improved hydrologic prediction capability).

The GAPP science plan notes that the linkage between the science (hydrology) and applications (water resources) activities within GAPP is particularly important. GAPP, like GEWEX, is a science program, which nonetheless also has a set of applications objectives. In this case, the scientific requirements have to do with better understanding the large scale hydrologic processes over the GAPP domain, how they influence hydrologic predictability, and in turn the development of hydrologic prediction tools. **With respect to time scale, the focus is on relatively long lead times (e.g., climate time scales of months to years). The applications objective is to improve operation of water resource systems using GAPP science.**

To understand how improved hydrologic forecast information can be produced, collaborative studies between the academic community and operational hydrologic forecast agencies, such as the National Weather Service, the GAPP science plan envisions implementing, in a manner similar to its current arrangement with NCEP, parallel research and operational pathways. The research pathway will be conducted primarily by scientists in the academic and government research laboratory community. The GAPP science plan calls for the operational pathway to be conducted primarily within the U.S. National Weather Services' Hydrology Laboratory, and its affiliated River Forecast Centers. **The NWS operational pathway would deal primarily with development of improved long-range hydrologic prediction capability, through testing and implementation of GAPP hydrologic modeling advances.** A second set of parallel activities would be implemented in conjunction with selected water management systems and agencies. These activities would test the implications of improved hydrologic forecast products for system operation. The parallel pathway approach is designed to make GAPP research accessible to water managers, and to provide a mechanism for feedback to the related science community.

The hydrology and water resources section of the GAPP science plan identifies six science questions that will be addressed through competitive research projects conducted by the academic community. The GAPP science plan also envisions that the GAPP research program will be carried out through a set of activities, to be organized around individual GAPP supported research projects, related non-GAPP research projects, related operational activities of the NWS hydrology program, and other activities of NASA, NOAA and other agencies. These activities will be structured within parallel research and operational pathways, following the successful GCIP model in the coupled modeling area.

The overarching GAPP strategy for hydrologic prediction, and its incorporation into water resources decision making, follows the so-called "Shukla Staircase" outlined at the 1998 GCIP "Visions Meeting" (Wheaton, MD). The steps involved in implementing this are:

1) Re-scale and downscale seasonal to inter-annual forecasts of precipitation and surface meteorology (from the continental or regional scale climate prediction models) to the time and space scales required by macroscale hydrologic forecast models;

2) Assimilate observations (e.g. precipitation, surface meteorology, snow cover and water equivalent, streamflow and surface skin temperature) into the hydrologic forecast model(s) to estimate initial conditions.

3) Implement hydrologic models in an ensemble mode using the forecasts and initial conditions.

4) Operate a hydrologic uncertainty post processor to adjust the hydrologic forecasts to account for effects of hydrologic biases and to assure validity of probabilistic forecast information to be used by the water resources decision-makers.

Project activities are oriented toward integrating GAPP research into operational models, implementation tools, and practical understanding required to make end-to-end prediction a reality in the water management field. **The end result is to demonstrate that GAPP research can be used to produce *engineering quality* seasonal to inter-annual hydrologic forecast products that can be used in a reliable way as a basis for water management decisions.**

This work will support water resources applications of research results from GAPP in several ways:

1. Through improvements in both a) the National Weather Service River Forecast System (NWSRFS) used to provide hydrologic forecast products for AHPS and b) the NOAH LSM. This is expected to lead to improved skill of both precipitation and hydrologic forecasts.

2. Through analysis of NCEP precipitation forecast products, especially ensemble forecasts, at all NCEP model forecast ranges, including days (Eta model), weeks (MRF model), and months/seasonal/annual (global SFM and imbedded RCMs of Eta and RSM)

3. Through analysis of hydrologic products produced by the NWSRFS.

Activities of the hydrology component of the core project are organized into 3 areas:

1. Hydrologic ensemble prediction
2. National Long-range Hydrologic Prediction System (NLHPS)
3. Hydrological model development and application

FY2003 accomplishments and FY2004 proposed statement of work for each of these activities is as follows:

1. <u>HYDROLOGICAL ENSEMBLE PREDICTION</u>

This activity has two parts:
HEPEX (Hydrologic Ensemble Prediction Experiment)
AHPS Science Infusion

1.1 HEPEX (Hydrologic Ensemble Prediction EXperiment)

At the July, 2003 meeting of the GAPP Core Project External Review Committee a recommendation was made that the hydrology component of the Core Project should develop an activity, similar to LDAS, to facilitate community participation in the work of the Core Project.

At the subsequent GAPP PI meeting in July, 2003 in Seattle, several of us informally discussed the possibility of establishing a hydrologic ensemble prediction project (HEPEX) that would be a GEWEX activity that would be over-seen by GHP/WRAP. We prepared a draft proposal that was well received by everyone we sent it to.

At the last GAPP PI meeting in September, 2004 in Boulder it was decided to begin a GAPP Ensemble Project that would be a U.S. contribution to HEPEX. Allen Bradley and John Schaake were designated project leader and co-leader, respectively.

The main objective of HEPEX is to bring the international hydrological community together with the meteorological community to demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence to assist the emergency management and water resources sectors to make decisions that have important consequences for the economy and for public health and safety. Representatives of operational hydrological services and operational water resources agencies are expected to participate in helping to define and execute the project. This objective can be achieved if the meteorological, hydrological and water resources communities understand the key challenges they face and work together both to couple currently available forecasts tools and to improve the current quality of available systems.

Many scientific questions need to be addressed for operational hydrological services to use these techniques to their full potential. Examples of these questions include: What are the properties of weather and climate forecasts? How can weather and climate information, including ensemble forecasts, be used reliably? How can the space and time scale properties of weather and climate forcing together with space and time scale properties of hydrological systems be best integrated in a hydrological ensemble prediction system? How does the uncertainty in weather forecasts translate into hydrological uncertainty? How can uncertainties in hydrological models, model parameters and hydrological initial conditions be represented in hydrological ensemble prediction? How do long-range Ocean-Atmosphere phenomena (i.e. El Niño) affect short- medium- and long-range hydrological forecasting? What is the relative role of weather and climate forecasts vs initial hydrological conditions in affecting the skill of hydrological forecasts? How can hydrological ensemble forecasts be verified, and what can be done to gain confidence that a given forecast system is reliable? What is the role of a human forecaster? What interface is needed for forecasters to control the operation of a hydrological ensemble forecast system? What is the experience of different groups throughout the world with ensemble hydrological prediction? What are the key science questions that need to be addressed by the HEPEX science plan? These questions need to be expanded and, in some cases, clarified. To address these, we need to collect data in lots of areas and work together.

Team members involved in this activity include: John Schaake (OGP funding) and Pedro Restrepo and D.J. Seo (OHD funding)

FY2004 Accomplishments

The first HEPEX workshop was held at ECMWF, March, 2004. The workshop was attended by 80 participants from 16 countries. The workshop enthusiastically endorsed the project. A summary report of the workshop was completed in August 2004. Roberto Buizza, ECMWF and John Schaake, NWS/OHD are co-chairs of the project. The summary report is also a preliminary science and implementation plan.

Several international demonstration projects we identified. Several of these are in Europe and are funded or are proposed to be funded by the European Union. The European projects include a pan-European forecast system being developed an operated by the EU Joint Scientific Center at Ispra, Italy, a potential project for the Danube being developed by Germany and Austria, and several EU research projects (including MUSIC and ACTIV). The Canadians have initiated a Canadian HEPEX project as a joint effort between the Canadian Meteorological and Hydrological services and the Hydropower industry in Canada. The NWS is conducting demonstration projects at 4 River Forecast Centers. Professor Peter Webster is leading a hydrologic ensemble prediction project for the Monsoon period in Bangladesh. We are discussion other projects in Brazil and Austrialia.

At the GAPP PI meeting in Boulder, September, 2004, it was agreed to begin a GAPP Ensemble Project that would be a US contribution to HEPEX. Allen Bradley is the project leader and John Schaake is co-leader. Allen prepared a draft plan in December, 2004. It is ready to be distributed for comment to the GAPP community.

We attended several scientific meetings and conferences where we made presentations about HEPEX and invited scientists to become involved in the project. These included EGU (Nice), Spring AGU (Montreal), Fall AGU (San Francisco), UNESCO workshop on extremes (Koblenz, July, 2005). Special sessions on Ensemble Prediction and HEPEX are planned for EGU(2005) and Spring AGU(2005). The GEWEX Hydrometeorology Panel was briefed on HEPEX in September, 2004 and the GEWEX executive committee was briefed at the University of Maryland in August, 2004.

At an ensemble prediction workshop at NCEP in November several of the leaders of a planned THORPEX project (TIGGE for THORPEX Interactive Gran Global Ensemble) suggested that we should develop a joint HEPEX/THORPEX hydrologic ensemble collaboration. The TIGGE project will produce experimental multi-model ensemble forecasts for lead times out to 2 weeks which overlaps into the intraseasonal timeframe of the climate program. We proposed that an important part of this would be a hydrological basins project that would enable PI level research on scientific issues that would use TIGGE ensemble data sets to meet HEPEX goals. The hydrological basins would include the basins being used in the MOPEX project. This proposal has been discussed with colleagues at the 2004 Fall AGU meeting and at the 2005 AMS annual meeting and has been received with enthusiasm. There will be a TIGGE planning workshop at ECMWF in March, 2005. We have been invited to participate.

FY2005 Statement of Work

Participate in the TIGGE workshop at ECMWF in March

Conduct second HEPEX workshop at NCAR in July, 2005

Complete establishment of HEPEX Science Steering Group (SSG)

Complete establishment of HEPEX User's Council

Convene special sessions at AGU Spring Meeting and EGU Annual Meeting

Report on HEPEX at IAHS meeting in Brazil in April and invite participation.

1.2 AHPS Science Infusion

Their currently are 3 core project activities underway to support Science Infusion to improve AHPS Ensemble Prediction. These are:

Hydrologic application of ensemble precipitation/temperature forecasts
Hydrologic model post-processing for user application
Retrospective ensemble verification

1.2.1 Hydrologic application of ensemble precipitation/temperature forecasts

This activity contributes to the planned GAPP activity to analyze global and regional model ensembles from different perspectives. One is to evaluate their forecast skill and to develop quantitative measures of this. Another is to evaluate the validity of probabilities estimated from the ensembles and to develop methods for correcting for biases in the model forecasts. Because these ensemble products are for coarser space and time scales than the data input requirements of hydrologic forecast models, techniques to re-scale and down-scale the ensemble information must be developed and tested. The GAPP science plan envisions that this activity will be carried out in cooperation with the NWS Advance Hydrologic Prediction Services (AHPS), parts of which may be treated as an NWS contribution to the operational pathway.

Accordingly, the Core Project has been collaborating with AHPS to develop methodology to analyze and apply ensemble precipitation forecast products for use in hydrologic forecasts, and to develop risk/uncertainty assessment information to help water resources managers. The focus of this work is on the application of intraseasonal to seasonal ensemble products. However, the scientific basis for this is essentially the same regardless of the forecast time horizon. Because there are many more short range and intermediate range events and because there is more experience and available historical forecast archive of these events, the ensemble investigations will include all time horizons.

One element of this work is to develop and demonstrate validation techniques that can discriminate which of several alternative ensemble forecast systems is preferred from a user perspective. This will include informativeness measures that define the resolution (i.e. skill) of the forecasts as well as calibration measures that define the reliability of the forecasts.

Another element is to suggest performance measures that can be used administratively to show steady improvement in NOAA's services.

Team members involved in this activity include: John Schaake, Shuzheng Cong, Sanja Perica and Martyn Clark (OGP funding) and Julie Demargne, D.J. Seo, Limin Wu, Edwin Welles and Hank Herr (OHD funding). Tom Hammil (CDC) provides advice as well as retrospective ensemble forecasts, from NCEP's GFS.

FY2004 Accomplishments:

Continued to analyzed global model ensemble forecasts of precipitation. Obtained the ensemble precipitation reforecast data set for NCEP's GFS that was produced by CDC with funding from OGP. Produced 1/8 degree grid of daily precipitation on 12z-12z clock that is consistent with NWS RFC operations and used this to develop a wide range of scale-dependent verification statistics for scales ranging from 1/8 degree to 2.5 degree. These data will be used during the next year to develop AHPS ensemble applications.

Completed a scientific paper for submission to the Journal of Hydrometeorology documenting the short and medium range ensemble precipitation and temperature preprocessors that we developed for AHPS. This development has included collaboration with Martyn Clark at University of Colorado/CIRES, Tom Hammil, CDC and Zoltan Toth, NCEP.

Developed a new version of AHPS preprocessors that includes: short and medium term temperature preprocessors, techniques to apply CPC probability shift products and procedures to use smoothed climatological statistics to generate ensemble precipitation and temperature forcing for periods where there is no skill in CPC forecasts.

Extended CNRFC pilot project to include several basins on the North Coast of California. Updated CNRFC preprocessor parameter values. Continued to monitor demonstration projects at ABRFC, CBRFC and MARFC. Provided updated preprocessor parameters for ABRFC and MARFC demonstration basins. These projects have shown that: (i) reliable preprocessor parameter estimation requires a substantial amount of historical data, (ii) existing hydrological ensembles have major spread problems and (iii) improved data assimilation and hydrological post processing techniques are needed.

Continued to compile verification statistics for ensemble forcing project results to date. Current results show that several years of archive of pairs of forecasts and corresponding observations are required to have stable verification statistics.

Continued to explore alternative approaches to reduce uncertainty in parameter estimates used in the ensemble forcing procedures in the current RFC pilot projects. Developed basis for a strategy to use the GFS reforecast ensemble data from CDC to improve parameter estimates.

Acquired additional operational ensemble forecast data sets from NCEP. Our previous archive of operational forecasts ended in 2000. We began to examine the correlation between the archived operational ensemble forecasts and the forecasts from the fixed version of the GFS supplied by martyn Clark and CDC. We found very high correlation between ensemble mean forecasts of daily precipitation for day 1 but very little correlation between daily ensemble mean values at longer lead times.

Continued collaboration with Zoltan Toth to develop procedures to calibrate atmospheric ensemble forecasts for application in AHPS. One result from this collaboration is that hydrological users of NCEP ensemble products need to be intimately involved in the development of the calibration procedures.

FY2005 Statement of Work:

Continue hydrologic ensemble pilot project at CNRFC for the American river basin inflow to Folsom reservoir and selected North Coast Basins. Develop capability to extend lead time to 14 days.

Continue to develop ensemble precipitation verification procedures and apply them to compare of different ensemble forecasts.

Continue to evaluate results of pilot application of simplified precipitation ensemble forecasts in the MARFC, ABRFC, CNRFC and CBRFC areas

Develop a strategy together with Martyn Clark for the CIRES/RISA project to accelerate infusion of global ensemble forecasts into AHPS.

Develop an ensemble downscaling procedure to preserve both forecast skill and account reliably for uncertainty over a range of time and space scales relevant to the existing RFC ensemble forcing pilot projects.

Continue to acquired additional ensemble forecast data sets from NCEP and CDC for both regional and global ensemble forecasts

Continue to update parameter values used in existing RFC ensemble forcing pilot projects

1.2.2 *Hydrologic model post-processing for user application*

The Core Project will collaborate with the scientific community and with AHPS to determine how to compensate for limitations, biases and uncertainties in ensemble streamflow predictions to assure valid probabilistic forecast products. This task is essential to production of *engineering quality* long range hydrologic forecasts required for water management decisions. Probabilistic outputs from all hydrologic forecast models include biases, not only in the mean but in all of the higher moments of the forecast probability distribution. This is a problem that is inherent in all models, including the atmospheric and coupled ocean-atmosphere forecast models. The technique of correcting for the effects of these biases is a generalization, for climate prediction, of the Model Output Statistics (MOS) solution that is widely used in weather forecasting to relate forecast model variables to observed local surface weather variables.

Essentially what is needed are model output calibration approaches that consider both the climatology of the event being forecast and the climatology of the forecast of the event to develop a transformation from the values produced by the forecast model system to values that have reliable statistical properties. Techniques to do this have been developed for application in AHPS, but they require testing and evaluation by the academic community.

Team members involved in this activity include: D.J. Seo and Hank Herr (OHD funding) and John Schaake (OGP funding)

FY2004 Accomplishments

Developed scientific paper describing an initial set of hydrologic post processing techniques we are planning to use in AHPS.

Applied the simplest of these procedures to ensemble reforecasts for the North Fork of the American river, California and demonstrated that it helped to remove mean bias but did not help to deal with problems with the spread of the hydrograph ensembles.

FY2005 Statement of Work:

Review experience gained in the Juniata river basin and suggest improvements to the ESP post processor procedures.

Continue retrospective tests in the Des Moines river basin. Apply verification procedures to Des Moines basin forecasts with and without application of error model post processor procedures

Continue to develop the procedures and test new approaches in the North Fork of the American River.

1.2.3 Retrospective Ensemble Verification

The Core Project will collaborate with the scientific community to develop methods for verification of ensemble forecasts and to conduct field tests using these verification procedures to evaluate potential improvements to AHPS and to test the applicability of AHPS products in different River Forecast Centers. Unless improved hydrologic verification procedures are developed and demonstrated, it will be basically impossible for GAPP to demonstrate that it has contributed anything of practical value to improve hydrologic forecasts. Therefore, this task is critical to GAPP's success and to establishing a scientific basis for the academic community to demonstrate the value of its accomplishments.

Team members involved in this activity include: John Schaake and Shuzheng Cong (OGP funding), Julie Demargne and D.J. Seo (OHD funding), Robert Hartman, Billy Olsen and Dave Brandon (NWS Regional operations funding) and Allen Bradley (OGP and OHD funding)

FY2004 Accomplishments

Collaborated Allen Bradley to develop verification techniques for AHPS ensemble forecasts. One of the problems with hydrologic ensemble verification is that the number of events available for verification are very limited. We initiated a project with Allen Bradley to analyze the uncertainty in verification statistics and to devlop guidelines for hydrologic ensemble verification.

Continued to develop a generalized AHPS ensemble verification subroutine that computes a large number of different verification statistics for a sample of ensemble forecasts. Input is a vector of observations and a matrix of ensemble member values corresponding to the observations. This subroutine will be used in all NWSRFS verification applications and provides a framework for infusing new ensemble verification techniques into NWS operations. Applied this for ESP verification for the American and Des Moines river basins. Developed verification statistics to measure problems with: (i) ensemble bias, (ii) spread and (iii) to distinguish these from random sampling noise.

Conducted retrospective forecast verification study of ESP for a headwater basin of the Des Moines river. We found major spread problems that are consistent with those found in the American river.

FY2005 Statement of Work:

Continue to add capability to the AHPS ensemble verification subroutine. Include verification procedures developed by Allen Bradley, Holly Hartman and Kristie Franz in AHPS ensemble verification procedures. Integrate additional results from OHD funded verification projects.

Apply NWSRFS ESP Verification System (ESPVS) to make retrospective forecasts for the American River Inflow to Folsom Reservoir

2. National Long-range Hydrologic Prediction System (NLHPS)

The NOAA GAPP Core Project will collaborate with NCEP and the University community to develop a system to produce probabilistic hydrologic forecasts for lead times from a month to a year. This will be an integral part of the AHPS program. The initial focus will be on experimental forecasts of natural runoff. If it can be demonstrated that valid long-range runoff forecasts can be produced from this system, a national NWS long-range runoff forecast product will be developed. This product will use RFC produced runoff forecasts where they are available and the results of the NLHPS where they are not. This system will use AHPS ensemble pre-processors to provide the ensemble forcing for the NLHPS hydrologic model(s).

FY04 Accomplishments:

Improved capability to process CPC models and data to simulate monthly streamflow for the historical period of record. This will provide a simulation version of the NLHPS.

Integrated Simple Water Balance (SWB) model into the simulation version of the NLHPS.

Continued discussions to develop collaboration with Dennis Lettenmaier, Eric Wood and Upmanu Lall in the development of an experimental National Hydrologic Long-range Prediction System

FY05 Statement of Work

Develop an historical monthly runoff analysis for the CPC climate division areas.

Develop a strategy to use the runoff analysis results to remove biases from the monthly hydrologic models to assure reliable simulations and improve model parameter estimates.

Develop a strategy for a forecast version of the NLHPS that will use CPC precipitation and temperature probabilistic forecasts together with AHPS ensemble preprocessing techniques to use the CPC forecasts.

Develop a strategy for retrospective verification of the resulting forecast version of the NLHPS.

3. Hydrologic Model Development and Application

This activity currently has two parts:

Land Data Assimilation System (LDAS)
Distributed Model Intercomparison Project (DMIP)

3.1 Land Data Assimilation System (LDAS)

The Core Project will collaborate with the LDAS project to support hydrologic validation aspects of the project, to support participation of the Sacramento model as one of four primary land surface schemes, to assist in intercomparison of results, to develop and coordinate collaboration between LDAS and RFC's, and to support hydrologic verification of the results.

FY2004 Accomplishments:

Developed proposed new *a priori* parameter estimation procedures for hydraulic parameters in the Noah model.

Conducted diagnostic studies of the retrospective daily LDAS precipitation grids for the western U.S. and part of the eastern U.S. for the period 1961-1990 to assure that the climatology of these grids is consistent with the PRISM precipitation climatology in the west for the same period.

FY2005 Statement of Work:

Continue to support the Sacramento Model operations.

Monitor results of adjustments to potential evaporation computations that were made in FY2003

Continue diagnostic studies of the LDAS precipitation estimation procedures.

3.2 Distributed Model Intercomparison Project (DMIP)

The hydrology and water resources component of the GAPP science plan includes several hydrologic model intercomparison studies. A potential contribution of the extensive land surface model development accomplished during GCIP is to improve the models used in hydrologic forecasting. For example, existing hydrologic forecast models do not have well developed representations of vegetation, they do not explicitly account for energy flux and storage, and they were not designed to make use of satellite remote sensing data. On the other hand they were explicitly designed to make good estimates of runoff and streamflow. An important next step is to compare the performance of current operational, and alternative research models in terms of hydrologic forecasting.

The goal of the Distributed Model Intercomparison Project (DMIP) is to consider alternative approaches to modeling the area upstream from several forecast points. This includes spatially distributed precipitation and basin characteristics of the upstream at different levels of detail. The goal is to evaluate alternative models relative to the existing NWS operational NWSRFS when operated in both lumped and distributed models. The results are being used help guide future distributed modeling research and would to improve the application of spatially distributed models used by operational forecasting offices.

More than a dozen participants from different parts of the world as well as the U.S. are participating. The LDAS project of this Core Project is an important partner to the DMIP initiative, providing forcing data sets, candidate distributed models, and a real time demonstration to complement the retrospective nature of the DMIP. The DMIP project promises to be an early success of the GAPP project in demonstrating the practical utility of GAPP and GCIP research for hydrologic prediction.

FY2004 Accomplishments:

The DMIP special issue of the Journal of Hydrology was published.

Continued planning for a new phase of DMIP (DMIP2) in the western mountainous U.S.

FY06 Statement of Work:

Continue planning for a new phase of DMIP2 in the western mountainous U.S. Assist in the development an analysis of data sets for DMIP2.